NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

NASA Grant NGL 44-012-006

THIRTEENTH SEMIANNUAL REPORT OF ACTIVITIES AND EXPENDITURES

1 April 1970 - 30 September 1970

Submitted by

Electrical Engineering Research Laboratory
MILLIMETER WAVE SCIENCES
The University of Texas at Austin
Austin, Texas

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A. W. Straiton, Director

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I. INTRODUCTION

This is the Thirteenth Semiannual Report of Activities of The University of Texas supported by NASA Grant NGL 44-012-006 (1 April 1970 through 31 March 1971). The grant for the purpose of investigating the millimeter wavelength electromagnetic radiation from bodies of the solar system is directed by Dr. A. W. Straiton and Dr. J. R. Cogdell.

This report summarizes the work carried out during the reporting period, within the framework of the overall objectives of the program in millimeter radio astronomy within this Laboratory. Two technical reports will be prepared to explore in more detail some areas included in this report. These are on: the scientific merit of the planetary program in the millimeter windows, particularly the 2 mm window, and the observational techniques which are employed in the planetary program, with the results to date.

The work reported in the following is organized under the headings of engineering programs and astronomy programs. Under the former heading we described principally the progress made in improving the sensitivity of the receivers in use on the radio telescope. This is a critical area for the observational program and the report is very encouraging.

In the second area we discuss first the lunar measurements which we are conducting in cooperation with NASA George C. Marshall Space Flight Center, Space Science Division. This work, whose scientific objectives fall outside the specific objectives of this contract, is included because of its relevance to the general astronomical program at the observatory.

Finally the general state of the planetary program is presented. Here we go into some detail in describing the observational procedures and the structure of the data analysis programs about which the major work during this period has centered.

II. Engineering Programs

A. Antenna Work

The general state of the antenna calibration is reported in our Report, TR NGL-006-70-1, "Evaluation of Reflector Antennas," by John H. Davis. The antenna is well calibrated throughout its useful range up to 140 GHz (λ = 2.1 mm). This work was the Ph.D. research of John H. Davis and has been summarized by publication in two papers, "Antenna Efficiency by Frequency Scaling Techniques," (to appear in IEEE PG-AP in February, 1971) and "Random and Systematic Phase Errors in Reflector Antennas," (in preparation). The only work done during the reporting period on the antenna was a re-evaluation of the pointing parameters. The general techniques used in this re-evaluation were those described in our report, "Point Evaluation of the 16 Foot Antenna."[4] The results of this study are similar to our earlier one, except that the polar axis direction changed by .013°. Within the region of the sky where most observations are made, this would cause errors of the order of .008°, which borders on the significant. Of more concern is the discovery that the mount is not absolutely stable. We currently anticipate repeating these tests throughout the coming winter season to monitor possible changes.

B. Receiver Work

This series of reports has contained a number of lamentations about the general unavailability of state-of-the-art mixers at millimeter wavelengths. This situation no longer prevails, with two vendors now offering good mixers in this wavelength range. During the reporting period, bids were gathered on new mixer-amplifier detectors for our 3 mm and 2 mm receivers. Due to a lack of funds only the 2 mm unit was ordered. The specifications are:

Noise Figure	15.9 dB (double sideband)
Gain (r.f. to i.f.)	60 dB
Bandwidth	300 MHz
Mixer type	Balanced, block type

The contract for the mixer specified the availability and replacement cost for the mixer diodes. The incorporation of this mixer into the 2 mm receiver should lower the sensitivity (ΔT_{rms} for one second integration time) from approximately 20°K to 2.0°K. Since the required observing time for a specified accuracy goes as the square of the sensitivity, this represents a vast improvement in the system.

The ultimate sensitivity limit which can be achieved is dictated by the fluctuations of the thermal emissions of the atmosphere. The new mixer will place us for the regime where these atmospheric fluctuations should be observable and annoying. The technique of beam switching[1-3] has been found to reduce these fluctuations considerably. For this reason we have been experimenting with a moving-feed type beam switch. A prototype and the driver circuitry have been built and are under test.

The work on the Josephson-junction detector which has been discussed in these reports has been slowed considerably by the departure of Bruce Ulrich to France for a year. In his absence we are proceeding with some basic experiments in superconducting junctions for the purpose of gaining experience in the relevant experimental techniques.

III. Astronomy

A. Lunar Program

In cooperation with Mr. Ted Calvert of the NASA Marshall Space Flight Center, a program of lunar studies has been initiated. The basic goals and division of responsibility has been reported earlier. During the reporting period, the following were worked on:

1. Lunar Ephemeris. A basic ephemeris computer program was developed and tested. The program uses some of the JPL ephemeris tapes and primarily interpolates the tape data and makes corrections for the antenna mount. The pointing accuracy is of some importance since the properties of specific Apollo sites will be studied. A careful check of the pointing accuracy of the ephemeris has yet to be made.

2. Experimental design. Through a series of meetings, the basic experimental procedures have been designed. During this procedure it was decided to simplify the goals and experimental procedures. In particular, it was decided to split off a polarization study as a separate experiment, as will be reported on below.

3. Practice Data. On June 24, 1970, Mr. Calvert and Dr. Cogdell went out to the Millimeter Wave Observatory to take preliminary data. The purpose was to chose from among several observing procedures, to test the ephemeris, and to gather some "real" data to use in developing data analysis computer programs. The weather cooperated and the trip was a success, observations being made at 3 mm. As a result of this trip, it was decided to use an "on-off" technique for the observations rather than an offset technique as originally proposed. We found that the latter method required too much skill on the part of the observers.

4. Data Reduction Programs. Primary responsibility for data reduction and interpretation rests with NASA/MSFC. The University of Texas has furnished some basic routines to NASA, e.g., routines that read and interpret the data cards, reduce calibrations, locate limbs, etc. At the present time the required programs are being coded at Huntsville.

Several lunar surface models have been developed by MSFC and investigated by NASA for comparison with the data.

5. Data Program. The initiation of the data taking phase of the experiment is awaiting the completion and testing of the analysis routines. The idea is to analyze the data within a short time of when it is taken. We currently hope to begin the observations during the winter.

6. Polarization Measurements. One proposed part of the measurements with NASA/MSFC has been separated off as a separate project. Terry White is to measure the polarization of the lunar radiation as a Master's thesis. This work is proceeding well at the present time and is to the data-

taking stage. The goals of this work is to investigate the effect of dielectric constant and surface statistics on the measurable polarization. One unique feature of this program in comparison with similar programs in the past is that we are taking particular care to measure the spurious effects which slight asymmetries in the antenna patterns can introduce.

B. Planetary Program

The basic goals of this contract is to make observations of the planets. When in December of 1969 the radio telescope became operative, a program of such observations was initiated and continued until 26 March 1970. The extent of the observations is indicated by the following table, which indicates the sources and frequencies observed.

	3 mm	2 mm
Jupiter	4 days	5 days
Saturn	13 days	0 days

The observations were terminated because we had no immediate means to analyze the results. At the present time, the necessary programs have been written, the previous data are being analyzed, and the observation program has been renewed. Thus the entire reporting period has been spent on essentially this data analysis problem, insofar as the planetary program is concerned.

It is not our purpose here to tax the reader with a step-by-step account of the problems and eventual solutions which measured the days and weeks. We do feel, however, that it would be helpful to outline the basic features of the observational and data handling procedures.

1. Ephemeris Calculation. An observing ephemeris is generated in advance. During the reporting period we converted our ephemeris programs to operate off JPL ephemeris tapes. Thus we have available pointing information on all the planets in addition to the sun and the moon. For observing, we compute the local coordinates (apparent hour angle and declination) correcting for refraction and antenna effects. How this ephemeris is used is described in the following section.

2. Observational Procedures. The observational data are divided into blocks called "scans." A full set of data consists of three types of scans: extinction, calibration, and drift scans. The extinction scans consist of solar drift scans during a sunrise or sunset period, the purpose of which is to measure the opacity (loss) in the atmosphere for the day. These scans normally appear at the beginning or end of the day's data but may appear in the middle or even may be interspersed with the other scans, i.e., the data program can handle all these possibilities. The calibration scans are for the purpose of monitoring the receiver gain and calibrating the output data in thermal units. These scans are typically four minutes long, with the calibration noise tube on for the central half. Such calibration scans are made throughout the observation period at 20 to 30 minute intervals.

The drift scans of the object, e.g., Jupiter, are made by setting the antenna at the position indicated by the ephemeris prior to its passage across that spot. The antenna then remains stationary relative to the earth and is carried past the object by the earth's rotation. By repeating this process, one is able to map the region around the source by changing the declination setting of the antenna from time to time. These drift scans take either 2 minutes at 2 mm or 4 minutes at 3 mm, the longer time being required in the latter case due to the need for adequate baseline with the antenna off the object. In each drift scan, the indicated antenna position and the timing of the data groups are recorded at the end of the scan. The antenna position is entered by the observer, while the time is furnished automatically by a digital clock.

A typical day's data might include 120 scans of which 10 would be opacity scans, 10 or more calibration scans, and the rest data (drift) scans. These data are recorded on a teletype in hard copy and paper tape form.

3. Data Reduction. Before computer processing of the data can be accomplished, the paper tapes must be translated to some computer inputable form. For ease of editing we have chosen to convert the data to cards. At our computer facility, this requires (1) placing certain special codes at the beginning of each paper tape (one day's observations can produce as many as three separate tapes), (2) translating the paper tape to magnetic tape, (3) translating these tapes to card images in the larger computer and punching the cards, and (4) interpreting the cards. Each of the four steps is done at a separate computer facility in a separate building.

The data are then edited to remove known operator errors and are ready for reduction. The data analyses program is diagrammed in Figure 1. Essentially the program reads one scan at a time, classifies its type, and reduces the data appropriately. In particular, the calibration

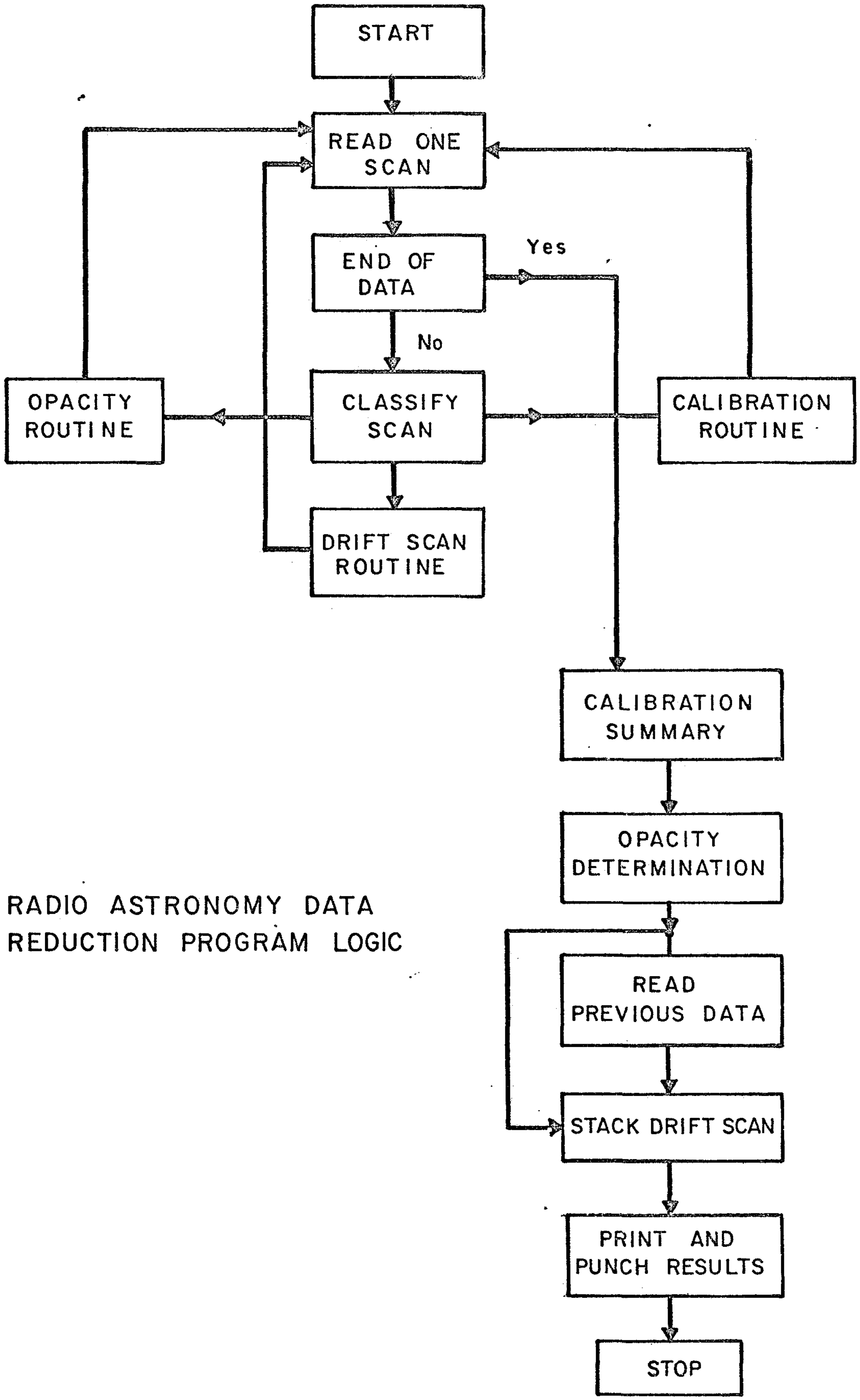

Fig. 1. RADIO ASTRONOMY DATA REDUCTION PROGRAM LOGIC

routine fits lines to the baseline and calibration and determines the scale factor at the time of the calibration. The opacity routine removes the baseline and determines the average deflection due to the sun, which is paired with the secant of the zenith angle. The drift scan routine (1) removes baseline and (2) calls on ephemeris routine and places each uncalibrated data point in a grid representing the area of the sky centered on the object of study.

In the termination phase of the program the calibration data is first regressed to yield an overall calibration function for the observation period. Then the opacity data are regressed against secant of the zenith angle (the number of equivalent atmosh eres) to yield the loss due to one atmosphere.

The final stage of analysis consists in reading previously analyzed data, if any, and averaging the new data with the old. In the process, the new data are corrected for extinction and calibrated to thermal units. The final result consists of a grid of values of the averaged antenna temperature on a grid of points centered on the object. These data are also punched on card for possible averaging with future data. The requirement to "stack" one day's data on the accumulated results of the past is a requirement imposed by our poor sensitivity.

The data displayed on the grid are then fit with a bell-shaped curve by one of several procedures and the scaling factors (antenna gain, source size) are applied to estimate the disc temperature of the planet.

C. Summary

The poor sensitivity of our receivers imposes the requirement that several days data must be accumulated for most planetary measurements. This constraint has forced us to adopt a rather complex observing procedure, which has in turn made the data reduction programs quite complicated. The problem of data reduction has received most of our efforts during this semi-annual period.

We now are considering alternative observational procedures which could possibly improve observing efficiency and simplify this problem. These will be detailed in a future report.

IV. BUDGET AND EXPENDITURES

The following expenditures between 1 April 1970 and 30 September 1970 have been made from the subject grant:

Salaries and Wages		
Professional	$10,831.83	
Student	7,573.31	
Supporting Services	1,191.28	
Total		$19,596.42
Instruments (Major)	$13,890.00	
Instruments (Minor)	1,229.83	
Total		$15,119.83
Travel, Communications and Reports	$ 1,494.40	
Miscellaneous	1,471.20	
Overhead and Other Indirect Costs	8,760.50	
Total		$11,726.10
Grand Total (1 April 1970 through 30 September 1970)		$46,442.35

Appropriated (1 April 1970 - 31 March 1971)

Appropriated (1 April 1971 - 31 March 1972)

Appropriated (1 April 1972 - 31 March 1973)

Step Funded

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4. Davis, John H. and J. R. Cogdell, "Pointing of the 16 Foot Antenna," Technical Memorandum No. NGL-006-69-3, Electrical Engineering Research Laboratory, The University of Texas at Austin, 15 November 1969.